Annual Growth of Contract Costs for Major Programs in Development and Early Production

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Summary

Cost is one of the key performance parameters of the defense acquisition system; cost is controlled and traded against schedule and technical performance of weapon systems. A new measure of cost growth (and thus cost control and tradeoffs) was developed to help look for longitudinal performance trends over the last three decades. This measure examines annual cost changes across major contracts for development and early production on major programs. This should not be mistaken for the total costs of these programs because it excludes non-contracted costs and the majority of production contracts. Nonetheless, we expect that the cost-reimbursement and fixed-price incentive contracts that this study examines should show the same trends as other measures of total program cost growth—in part because production contracts have much lower cost growth than these development and early production contracts. Such changes reflect added work and overruns after adjusting for inflation.

A 5-year moving average of the annual changes was used to smooth the data, revealing the patterns visible in Figure 1. Statistical analysis found that the combined effect of three types of factors—plus a constant base level of growth—accurately models growth on these contract (Figure 2 shows how closely the model fits the actual data).

First, the pattern of growth partially follows the defense budget. In other words, there is strong evidence that changes in budget have an effect but other factors also affect cost growth behavior.

Second, periods of structural changes contributed additional constant shifts in the growth. Two such overlapping periods saw reductions. One period runs from 1990 to the end of the data, coinciding with the era after the Goldwater-Nichols Act and other legislation that made major structural changes to the defense acquisition system. A second period runs from 2012 to the end of our data, coinciding with the implementation of the Better Buying Power (BBP) initiatives to emphasize cost consciousness, improve efficiency, strengthen acquisition workforce tradecraft, and seek ways to drive costs downward. These structural changes had fairly large effects: about a 1 percentage-point reduction in the Goldwater-Nichols era and almost a 2 percentage-point reduction in the overlapping BBP era. Interestingly, analysis showed that the apparent rise during the acquisition reforms of the mid-1990s seen in Figure 1 was correlated with budgetary changes rather than a structural increase in growth in these data.

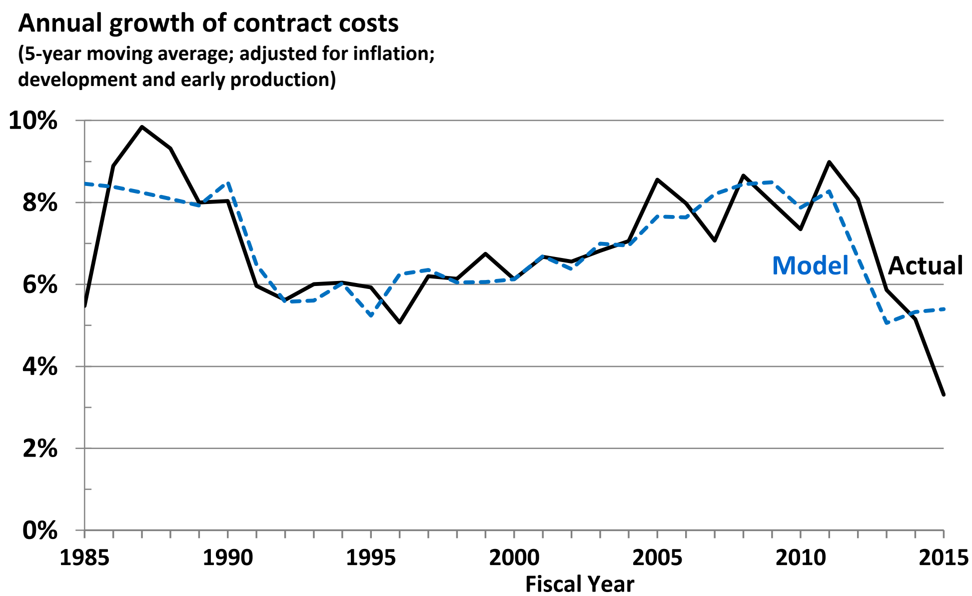
Third, these data exhibited a constant base growth of just under 5 percentage points (all other things being equal).

Finally, our modeling indicates that the defense system exhibits a self-correcting behavior that adjusts for prior differences between the actual growth and the anticipated cost growth from these budgetary, structural, and constant factors. Such a correction function adjusts for unforeseen external effects on the defense systems (including unanticipated changes in budgets) and internal variations (such as growth that is different than modeled in a particular year). This correction function serves as a kind of negative feedback that keeps costs under control.

Figure 1: Actual Growth of Contract Costs

NOTE: 5-year moving average of annual growth in contracted total costs relative to negotiated cost targets on major contracts of Major Defense Acquisition Programs (MDAPs), as well as major automated information systems (MAIS) that are MDAPs, in Engineering and Manufacturing Development (EMD) and early production that reported earned-value (EV) data (i.e., almost no firm-fixed price or full-production contracts). This is different than statutory measures of program cost growth relative to baselines. These data summarize 18,470 EV reports on 1,123 major contracts for 239 MDAPs.

Figure 2: Statistical Model Fit to Actual Growth of EV contract costs



In addition to identifying what does correlate with growth of EV contract costs, it is useful to say what does not. As we made clear above, none of this work relates to government costs or firm-fixed-price costs, which are the majority of production efforts. The two significant drops are not due to increased amounts of lower-growth early production contracts in those periods. In fact, early production levels have been relatively flat during the BBP era and dropping from 1990–2007. The reductions in the BBP period are mainly due to reductions in growth on development contracts.

They are also not due to schedule effects, since schedule growth has been flat during the BBP era and does not generally correlate overall with cost growth in these data.

Additionally, they are not due to quantity changes because other analysis of contract data since 2000 showed no quantity changes on these kinds of contracts (i.e., quantity changes are predominantly on full-rate production contracts, which are not in these data).

Furthermore, prior research tested a number of other variables for correlation with cost growth on these contracts since the year 2000, eliminating a large number of them.[1]

In conclusion, this analysis provides insights into the behavior of the defense acquisition system.

- *It behaves rationally.* It adjusts to budgets while reflecting that acquiring systems that have never been built before involves some cost risks.
- *It responds to major structural changes.* Recent efforts to strengthen the defense department's cost-conscious culture have improved cost control. Added oversight from the era of Goldwater-Nichols and contemporary changes also appears to have had a major effect at moderating contract cost behavior. However, the reforms of the mid-1990s did not have a large enough effect in these data to be measurable.
- *It is stable.* A feedback function self-corrects for prior differences from expectations and unforeseen external shocks.

Taken together, this analysis provides both an encouraging and cautionary tale that some reforms can moderate costs in this metric while others have not. This analysis also demonstrates how statistical analysis combined with theoretical insights deepens our understanding of the effects of policy changes and thus can inform future decision making without resorting to supposition.

[1] The following variables were either spurious or statistically insignificant: undefinitized contract actions (although UCAs can be significant in some commodity classes, especially ships in development); contract spending share of program spending; cost-over-target; share of cost growth due to work-content growth; share of cost growth due to cost-over-target; margin; change in margin over the contract's period of performance; contract size (total dollars); schedule growth; military service (i.e., Army, Navy, Air Force, or DoD); commodity type (except space systems in development and aircraft in early production); and quantity changes (see AT&L, 2015, pp. 75–77).

INTRODUCTION

Are there periods of improved cost control on defense contracts? Have recent efforts produced measurable results? What effects have external events and major policy changes had on controlling costs on major defense programs?

To help answer these questions, we examined the 5-year moving average of annual growth in total EV contract costs on major contracts[2] for the development and early production of Major Defense Acquisition Programs (MDAPs). Growth is in real terms (i.e., after adjusting for inflation). This different measure of growth reflects changes relative to negotiated costs targets on contracts tracked in earned-value (EV) reports. It includes both scope growth (i.e., work added to a contract after award) and overruns (i.e., latest estimate of cost over the latest negotiated target). Negotiated targets do not necessarily equal government or contractor negotiation cost estimates. These contract level targets are also different than broader program-level cost estimates, baselines, and statutory measures of cost growth relative to program-level baselines because it excludes non-contracted costs and the majority of production contracts. Nonetheless, we expect that the cost-reimbursement and fixed-price incentive contracts that this study examines should show the same trends as other measures of total program cost growth—in part because production contracts have much lower cost growth than these development and early production contracts. EV reports are typically limited to development (engineering and manufacturing phase) and early production contracts. They include fixed-price incentive and cost-reimbursement contracts but generally not firm-fixed price contracts (which often are not appropriate until full-rate production and usually do not report EV). Each year's growth is the sum of all the changes in active contract values divided by the sum of all the original target costs. Thus, the portfolio percentage change will be closer in value to the percentage change of the larger contracts. Of final note, reports of scope changes and estimates of final cost in EV reports can be sporadic, leading to wide year-to-year changes; therefore, we used a 5-year moving average to smooth out these effects and reveal longer-term trends.

We used standard statistical modeling techniques to identify statistically significant factors that are likely causes of growth. For example, are reductions merely reflections of budgetary reductions, or are there measurable structural shifts from major policy changes? Is the defense system stable in dealing with external and internal spikes and shocks? Of course, proving causation is difficult, but correlation and coincidence combined with insight into defense acquisition can provide valuable insights into causes.

[2] Major contracts include the six largest contracts (prime, associated, or for government-furnished equipment) for each MDAP valued at more than $40 million. Earned value data also are available for other MDAP contracts of at least $60 million in RDT&E or $250 million in procurement or ship construction (in fiscal year [FY] 1990 constant dollars). Note that EV data are usually not provided for firm-fixed price (FFP) contracts, so this MDAP contract dataset has very few FFPs.

ANNUAL GROWTH OF DEVELOPMENT AND EARLY PRODUCTION CONTRACTED COSTS

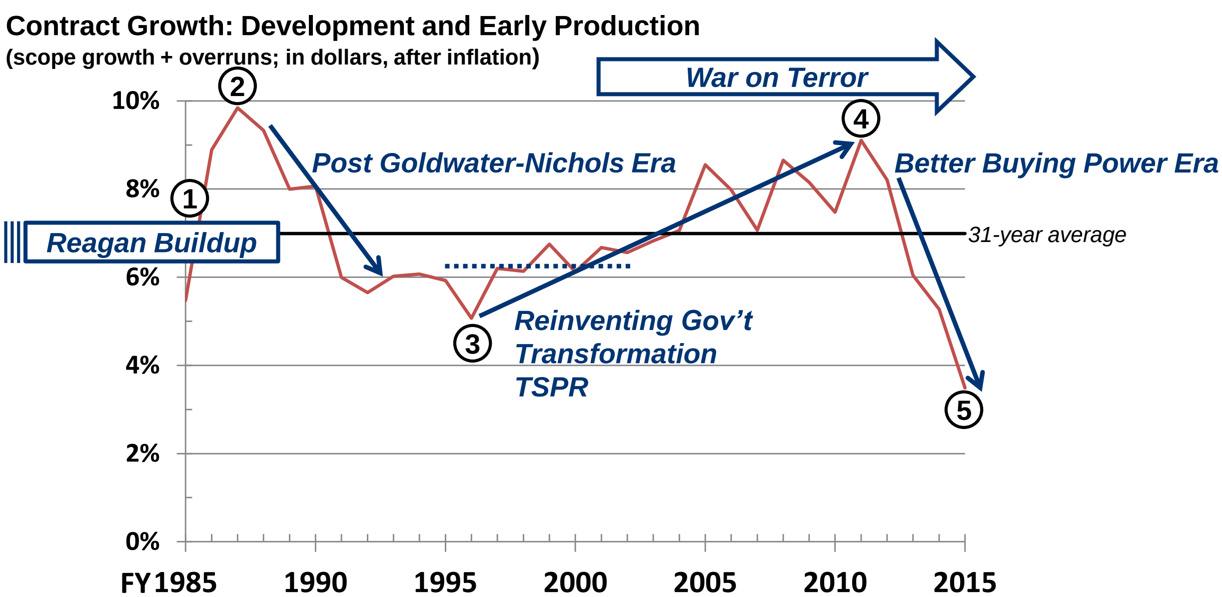
Figure 3 plots the 5-year moving average of annual growth in EV contracted costs on major contracts for MDAPs. It shows that some policy changes appear to have resulted in dramatic downturns in the growth of costs on executing contracts for these programs.

The Goldwater-Nichols Act of 1986—which reorganized the Department of Defense (DoD) and the contemporaneous legislation that strengthened oversight by the Office of the Secretary of Defense on defense acquisition programs—coincided with a major downturn in annual growth of EV contract costs at point #2 on the chart. Also, the initiation of the recent DoD initiatives called Better Buying Power (BBP) to instill cost consciousness, improve efficiency, strengthen the workforce, and seek ways to drive costs downward also coincided with the recent downturn starting at point #4. At 3.5% in FY2015 for the portfolio, the department is now at the lowest level of growth since before FY1985.

Conversely, policy changes starting in the mid-1990s that reduced oversight on contractor performance appear to coincide with an upturn in annual added costs on contracts from point #3. We test below whether that period increase is statistically significant (e.g., whether the trend is really flat from 1995 if you dismiss 1996 as anomalous).

Increased demands for new capabilities can also result in costs added to contracts; that is visible in the chart during the defense buildup in the 1980s by President Reagan and during the post-9/11 wars to combat global terrorism.

Figure 3: 5-year Moving Average of Annual Growth of EV contract costs (FY1985–2015)



NOTES: The 5-year moving average of annual growth in contracted total costs are relative to *negotiated cost targets* on major contracts of MDAPs (including MAIS that are large enough to also be MDAPs) in engineering and manufacturing development (EMD) and early production that reported earned-value (EV) data (i.e., include almost no firm-fixed price or full-production contracts). This is different than statutory measures of program cost growth relative to Milestone B baselines. These data summarize 18,470 earned-value reports on 1,123 major contracts for 239 MDAPs. TSPR = Total System Performance Responsibility.

FACTORS CONTRIBUTING TO ANNUAL GROWTH IN EV CONTRACT COSTS

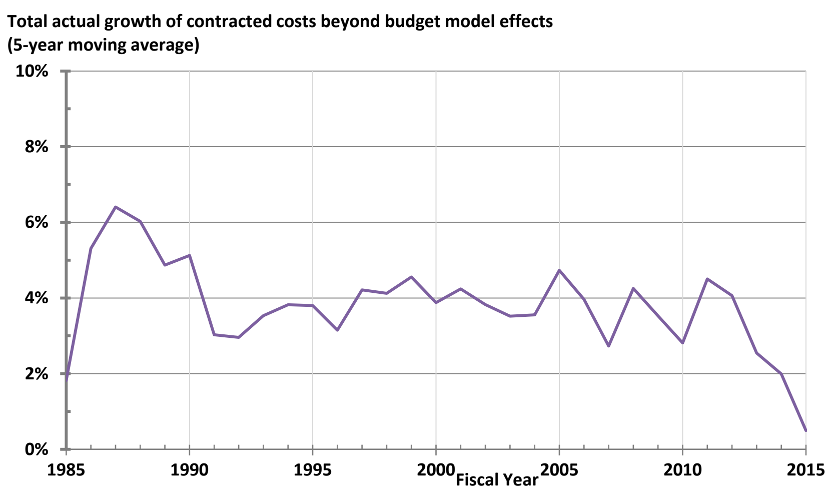
To understand whether the trends in Figure 3 are significant and what may be driving them, we employed the following statistical analyses. First, we wanted to determine whether the two steep drops are statistically significant and whether they are merely an artifact of budget cuts. We also wanted to test whether the growth in the mid-to-late 1990s was flat or significantly upward.

We found that the combined effects of three types of drivers—together with a constant base and random noise—very closely fit the dynamics of the growth curve.

1. *Budget effects*. The growth in costs is, in part, positively correlated with budget levels and dynamics. This includes two factors:
   - the average of the DoD budget over the past 5 years, and
   - the change in that average from the prior year to the current year.
2. *Two structural changes.* Two overlapping periods correlate with partial reductions:
   - one since 1990, coincident with post-Goldwater-Nichols implementation, and
   - one since 2012, coincident with BBP implementation.[3]
3. *A self-correcting behavior*. A factor that corrects for prior differences between the anticipated cost growth from the budgetary, structural, and constant factors and the actual growth. This autoregression factor adjusts for unforeseen external "shocks" to the systems (including unanticipated changes in budgets) and internal variations (such as larger-than-modeled annual contract obligations). It serves as a kind of negative feedback that keeps the system under control.

Of note, we also tested for structural change during the period of the mid-to-late 1990s (FY1995–2001) in the era of Reinventing Government. The effects in that era failed the statistical tests in these data (i.e., we cannot claim that they are statistically different from zero). Figure 4 shows that the growth during this period appears relatively flat after subtracting the partial budgetary effects.

Figure 4: Actual Growth Less Modeled Budget Effects (FY1985–2015)



[3] Since the effects of new policies take time to show, we measured these periods to start 2-3 years after their enactment. Goldwater-Nichols Act was signed into law at the start of FY1987, and the first BBP memoranda were issued in late FY2010.

Testing for Underlying Causes

What may be the underlying causes for the factors identified above? While it is difficult to trace changes to individual policy changes, we can identify some underlying drivers and rule out others.

Development and Early Production Differences

BBP-era drops are driven by dropping development cost-growth rates, not higher proportions of early production contracts. The recent downward trend is not driven by an increased fraction of early production dollars in the annual portfolios. Because growth on early production contracts has been lower than that for development since 1990, such a shift might have been a logical cause for the recent drop. In fact, however, the proportions between development and early production dollars have been relatively flat since 2012 (see Figure 5). Instead, the overall BBP-era drop is being driven by steep drops in the growth rates on development contracts (see Figure 6).

Initial Goldwater-Nichols-era drops are largely driven by dropping early production cost rates, not higher proportions of early production contracts. Similarly, the dramatic initial drop from FY1987–1991 as the Goldwater-Nichols era changes were first being implemented was driven mostly by steep drops in growth rates on early production contracts (see Figure 6). The proportion of early production dollars in the portfolio was mostly flat in this early period. After this initial period, both the development cost rate and proportions were increasing, so the overall Goldwater-Nichols era structural effect is not due to the development/production split or their cost dynamics.

Schedule Effects

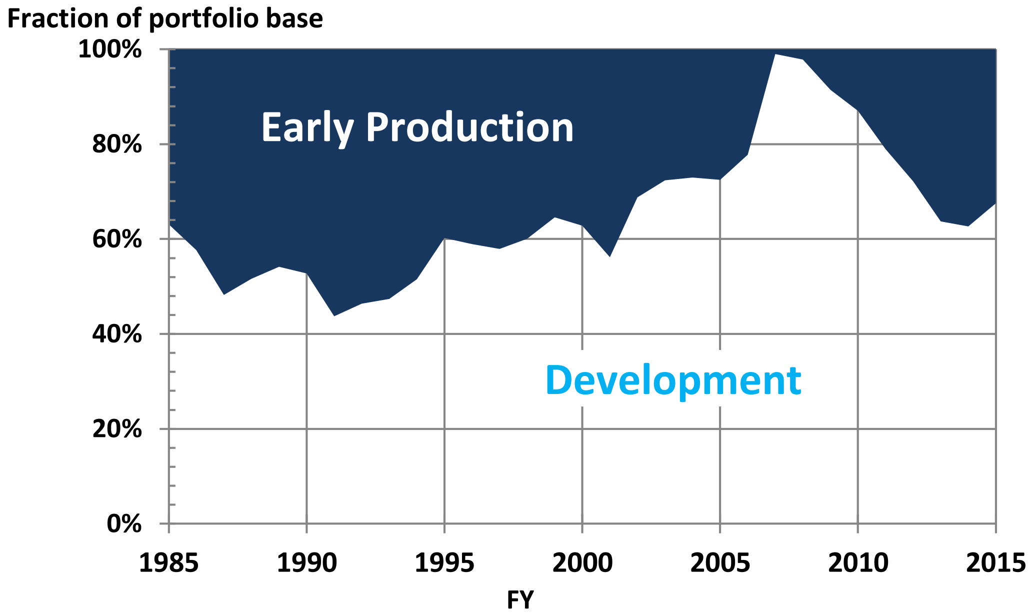
DoD generally was not adjusting schedule to lower costs. We were also able to reject the possibility that the DoD was simply adjusting contract schedules to lower growth of EV contract costs in the BBP era or overall. Overall, we found no correlation between growth of costs and schedule on these contracts. The 5-year moving averages of growth in annual schedules and EV contract costs are statistically independent.[4] We can see this in Figure 7, where cost and schedule growth were moving in opposite directions since about 2002.

Quantity Effects

These factors are independent of quantity changes. Lastly, we note that prior research showed that contract quantity almost never changes on these early production contracts—at least since about the year 2000 (see AT&L, 2015). Also, quantity generally is not an element on development contracts (except for relatively few test articles). Therefore, quantity is not an underlying cause for the factors in the statistical model or for the separate growth dynamics by development and early production.

[4] i.e., they failed the Spearman correlation test.

Figure 5: Portfolio Split between Development and Early Production Contracts



NOTE: This reflects the relative total dollars in the contract bases each year.

Figure 6: Separate Growth Rates for Development and Early Production Contracts

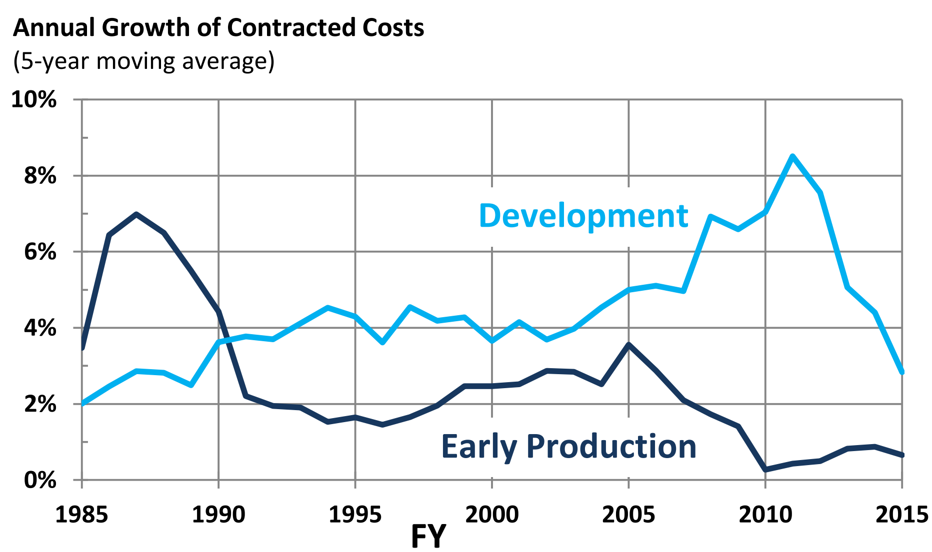
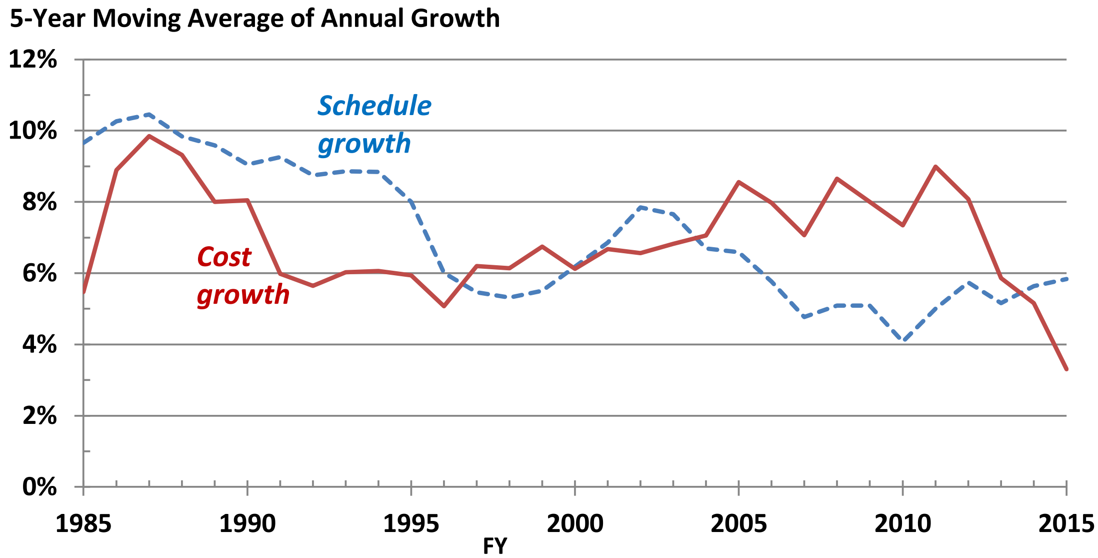


Figure 7: Comparing Growth in Schedule and Cost on Major Contracts (FY1985–2015)



NOTE: In the BBP era (since 2012), schedule growth is essentially flat while cost growth has dropped dramatically.

Cycle Time, Scope Growth, and Commodity Effects

Cycle time, scope growth, and certain commodities correlate with growth of costs in these data. Prior research did find three variables that generally correlate with growth in this type of contract data: the original length of the contract (i.e., cycle time, not schedule growth), scope growth, and two commodities (space systems in development and aircraft contracts in early production). Cycle time was the largest correlate (AT&L, 2015, pp. 75-77).

Should-Cost Reductions

Reduced cost growth in the BBP era may be due in part to Should-Cost savings. Finally, we note that the DoD has continued to see increasing savings on programs from Should-Cost initiatives in BBP. These savings have grown across the acquisition portfolio, so these may have additional effects in lowering scope growth and cycle time at the contract level.

Other Variables

Prior research tested a number of other variables that do not correlate with growth of costs on these contracts. Further, prior research tested a number of other variables for correlation with price and cost growth on these contracts since the year 2000. It found the following variables were either spurious or statistically insignificant: undefinitized contract actions (although UCAs can be significant in some commodity classes, especially ships in development), contract spending share of program spending; cost-over-target; share of cost growth due to work-content growth; share of cost growth due to cost-over-target; margin; change in margin over the contract's period of performance; contract size (total dollars); schedule growth; military department (i.e., Army, Navy, Air Force, or DoD); commodity type (except space systems in development and aircraft in early production); and quantity changes (see AT&L, 2015, pp. 75–77).

Conclusions

This analysis provides some insights into the behavior of the defense acquisition system.

- *It is stable.* The autoregression feedback provides a self-correcting control system.
- *It behaves rationally.* It adjusts to budgetary changes, prior differences from expectations, and unforeseen external shocks.
- *It responds to major structural changes.* Added oversight from Goldwater-Nichols Era changes appears to have had a major effect at moderating contract cost behavior. Similarly, recent efforts to instill a cost-conscious culture have improved cost control. The reforms of the mid-1990s were coincident with an undesirable trend, though unlike the positive trends, our modeling did not show statistically significant indications of causal factors.

Taken together, this analysis provides both an encouraging and cautionary tale that some reforms can moderate costs in this metric while others have not. This analysis also demonstrates how statistical analysis combined with theoretical insights provides useful insights into the effects of policy changes and thus can inform future decision making without resorting to supposition.

Acknowledgements

The authors would like to thank Gary R. Bliss and Philip D. Rodgers for helpful comments on early manuscripts of this report. Data availability was facilitated by archives maintained by Mark Krzysko and his organization.

ANALYTIC DETAILS

Data

We analyzed growth in contract cost using summary EV data on 1,123 major contracts from FY1981–2015 for 239 major defense acquisition programs (MDAPs). These included the combined results from 9,680 EMD reports and 8,790 early production reports. Table 1 lists the actual 5-year moving average of annual growth of EV contract costs as calculated using the equations below.

Table 1. 5-Year Moving Average of Annual Growth of EV contract costs (FY1985–2015)

FY	Growth (actual)		FY	Growth (actual)
1985	5.47%		2001	6.67%
1986	8.89%		2002	6.56%
1987	9.84%		2003	6.82%
1988	9.33%		2004	7.06%
1989	8.00%		2005	8.55%
1990	8.07%		2006	7.98%
1991	5.99%		2007	7.07%
1992	5.65%		2008	8.66%
1993	6.02%		2009	8.16%
1994	6.07%		2010	7.48%
1995	5.93%		2011	9.10%
1996	5.07%		2012	8.21%
1997	6.20%		2013	6.05%
1998	6.14%		2014	5.27%
1999	6.75%		2015	3.49%
2000	6.12%			

NOTE: Results reflect 18,470 earned-value reports on 1,123 major contracts for 239 major defense programs.

These growths are calculated across all contracts together by totaling the changes of the program manager's estimate at completion (PM EAC) in the year (i.e., from the last report from the prior year) for all contracts, then dividing by the sum of all the initial contract cost targets for all the active contracts in a year:

$$g(t) = \frac{\sum_{r=1}^{m} \Delta PMEAC_r(t)}{\sum_{i=1}^{n} CBB_i(original)}$$

for *m* reports on *n* contracts active in year *t*

where:

$g(t)$ is the average growth of contracted costs across all active EV contracts in year *t* (adjusted for inflation),
$\Delta PMEAC_r(t)$ is the change in contract cost as reported by the program manager's estimate at completion (PMEAC) for EV report *r* for an active program in year *t*, after adjusting for inflation,
$CBB_i(original)$ is the original negotiated cost target[5] at contract award for contract *i* in common base-year dollars, and
t is the FY for the annual growth.

Given g_t, the 5-year moving average growth G_t of EV contract costs for year *t* is simply

$$G_t = \frac{\sum_{i=0}^{4} g(t-i)}{5}$$

for $t \in [FY1985, FY2015]$.

[5] In EV reports, the Contract Budget Base (CBB) is the sum of the Negotiated Contract Cost (NCC) and the Authorized Unpriced Work (AUW).

Model of Annual Growth of EV contract costs

The following equations show our statistical model of the 5-year moving average of annual growth of EV contract costs on major MDAP contracts:

$$G_t = c_0 + c_1 B_{t-1} + c_2 \Delta B_t + c_3 GN_t + c_4 BBP_t + u_t$$
$$u_t = c_5 u_{t-5} + \varepsilon$$
$$\varepsilon \sim i.i.d.\ N(0, \sigma^2)$$

for $t \in [FY1985, FY2015]$.

where

G_t is the 5-year moving average of annual growth of EV contract costs at time *t*,

c_i are coefficient constants,

B_{t-1} is the 5-year average of the DoD budgets from time *t-5* to time *t-1*,

$\Delta B_t = B_t - B_{t-1}$ is the change in the 5-year moving average of the budget from time *t-1* to time *t*,

$GN_t = \begin{cases} 1\ for\ t \geq FY1990, \\ 0\ for\ t < FY1990; \end{cases}$ this is the indicator variable for a hypothesized structural change since FY1990 (i.e., the era of full implementation of the Goldwater-Nichols Act),

$BBP_t = \begin{cases} 1\ for\ t \geq FY2012, \\ 0\ for\ t < FY2012; \end{cases}$ this is the indicator variable for a hypothesized structural change since FY2012 (i.e., the era of full implementation of BBP),

u_t is an autoregressive factor for the difference between the actual growth and the growth predicted by the other factors 5 years earlier, and

ε is a series of independent and identically distributed (*i.i.d.*) samples from a normal distribution with zero mean (i.e., Gaussian white noise).

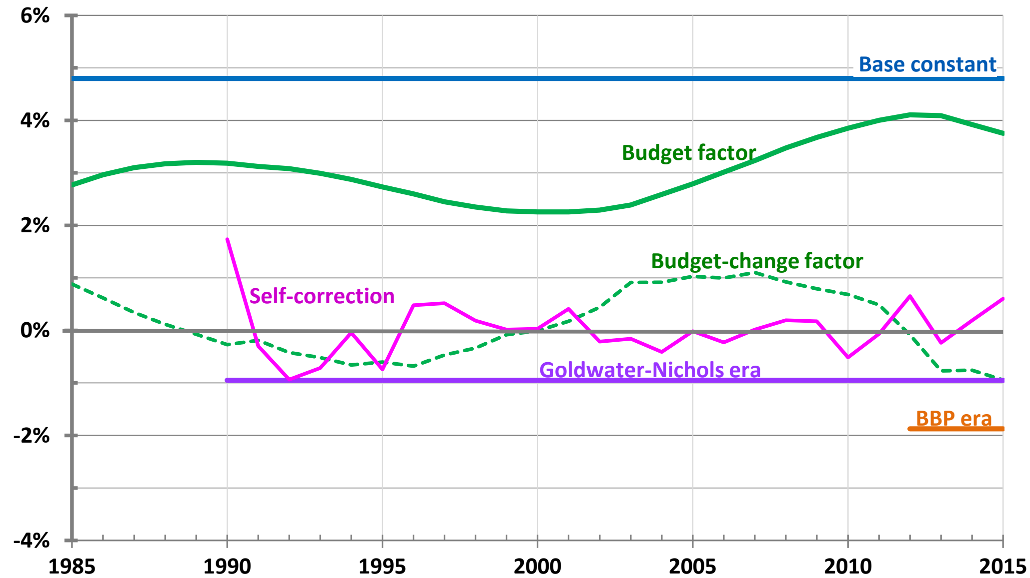
Table 2 lists the coefficients c_i for the statistically significant factors in the model of the 5-year moving average of annual growth of EV contract costs on major MDAP contracts reporting EV. Figure 8 shows the partial contributions of these drivers to the growth curve for each year from FY1985–2015, and Figure 9 shows the combined effect of the two budgetary variables. Recall that Figure 2 shows how closely this statistical model matches the actual growth in EV contract costs over this period; it uses the MLE coefficients.

Table 2. Model Coefficients and Statistics: 5-Year Moving Average of Annual Growth of EV contract costs

Driver Type	Factor	OLS (Newey West)	MLE (OIM)	MLE (OPG)	p-value OLS	p-value MLE (OIM)	p-value MLE (OPG)
Budget Effects	c_1 coefficient for each \$100B in the 5-year moving average of prior DoD TOAs from last year (standard error)	0.602% (0.0000195)	0.551% (0.0000197)	0.551% (0.0000319)	0.005***	0.005***	0.084*
	c_2 coefficient for each \$10B change in 5-year moving average of prior DoD TOAs from last year (standard error)	0.233% (0.0000788)	0.252% (0.0000587)	0.252% (0.0000729)	0.007***	0.000***	0.001***
Structural Effects	c_3 coefficient for Goldwater-Nichols era structural change, FY1990–2015 (standard error)	−1.07% (0.00526)	−0.948% (0.00457)	−0.948% (0.00434)	0.051*	0.038**	0.029**
	c_4 coefficient for BBP era structural change, FY2012–2015 (standard error)	−1.70% (0.00851)	−1.87% (0.00776)	−1.87% (0.00961)	0.057*	0.016**	0.051*
Self-Corrections	c_5 coefficient autocorrelation coefficient: correction amount of actual-to-model difference in prior year (standard error)	−0.334 (0.157)	−0.583 (0.208)	−0.583 (0.231)	0.044**	0.005***	0.012**
Base	c_0 coefficient for constant (standard error)	4.63% (0.0122)	4.80% (0.0120)	4.80% (0.0176)	0.001***	0.000***	0.006***

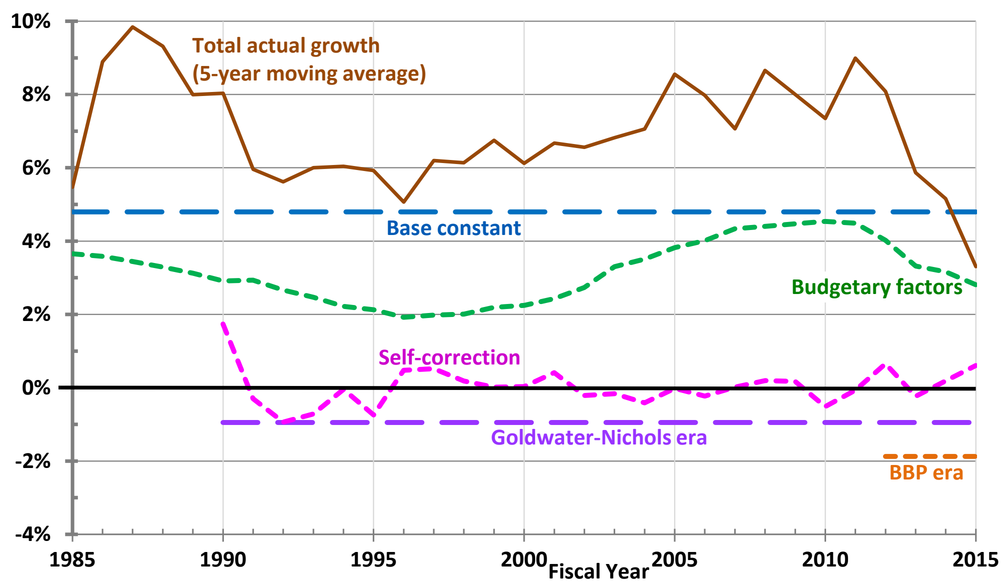
* statistically significant at the 10% level of significance. *** statistically significant at the 1% level of significance.
** statistically significant at the 5% level of significance
NOTES: These results are robust to the different estimation methods shown and to different ways of calculating the variance covariance matrix. The autocorrelation coefficients met stability conditions. After accounting for autocorrelations, the residual error was white noise.

Figure 8: Factors Contributing to 5-year Moving Average of Annual Growth of EV contract costs (FY1985–2015)



Factor	Partial Contributions (MLE model)
Base constant (overall)	4.8 %-points
Average budget over prior 5 years	+ 0.55 %-points per $100B
Change in 5-year average of past budgets from the prior year to current year	+ 0.25 %-points per $10B change
Post-Goldwater Nichols era structural change (since FY1990)	− 0.95 %-points
BBP era structural change (since FY2012)	− 1.9 %-points
Self-correction factor of difference between actuals and the other factors 5 years ago	− 0.58 times the overage 5 years ago
Randomness	+ pure noise

Figure 9: Factors Contributing to 5-year Moving Average of Annual Growth of EV contract costs: Combined Budgetary Factors (FY1985–2015)



In simple terms, this model (not surprisingly) indicates that the defense acquisition system modulates changes to major program contracts—in part—based on budgets: if there are more resources then the system addresses more issues such as threats and engineering issues that arise in development and early production. When resources are tight, the system addresses fewer of these problems. The combined partial effect is that growth changes somewhat in the same direction that budgets change (i.e., are procyclical), which can be seen visually in Figure 9. Cost change is expected to increase just over half a percentage point for every $100 billion in average budget over the prior 5 years. The model also predicts that cost changes will increase about a quarter of a percentage point for every $10 billion change in the 5-year moving average of past budgets from last year to the current year.

Also, there have been additional behavioral shifts to partially reduce growth on major contracts: one coincident with the implementation of Goldwater-Nichols to present, and one coincident with BBP implementation to present. These effects are large, statistically significant, and independent of budgetary dynamics. In the Goldwater-Nichols era, growth has been systemically moderated by about 1 percentage point, and growth has been reduced almost another 2 percentage points in the BBP era (all other things being equal). Measured against the peak annual growth of almost 10 percent in this period, these reductions constitute a systemic reduction of almost a third.

In addition, the department self-corrects for external and internal variations that ensures stability. If contract work grew in a year more than what we would expect from the model given budgetary trends, existing structural behaviors (say, because of critical threats), and prior corrections, then the DoD cuts back in the future. Conversely, if contract work grew less than expected, then the department tends to increase obligations in the following year to address problems. In other words, it shows that the defense acquisition system self-corrects for differences between what it anticipates it can obligate on contracts given recent budgetary effects under the then-current structural climates and what it actually put on existing contracts. In addition to external and random shocks, this factor may reflect a so-called "horsetail" effect wherein the DoD's 5-year future-years defense program (FYDP) plan usually fails to predict both downward and upward cyclic changes in actual budgets (i.e., being overly optimistic when budgets are declining and pessimistic when budgets are rising—see, for example, Lambert, 2014, p. 3, and Harrison, 2014, p. 21).

Lastly, there is a constant base of growth on contracts over all these years, reflecting that defense weapon system development and early production involves some remaining uncertainties, risks, and investments (including changes to keep up with evolving threats). The overall base of just under 5 percent annually, however, is relatively low given these are the more risky development and early production contracts, not full-rate production.

Model of Annual Contract Schedule Growth

Statistically we found that schedule growth has been on a simple downward trend along with its own one-year self-correction factor (see Table 3).

Below are the statistically significant factors in the model of the 5-year moving average of annual growth of contract schedules on major MDAP contracts reporting EV.

$$s_t = c_0 + c_1 Y_t + u_t$$
$$u_t = c_2 u_{t-1} + \varepsilon$$
$$\varepsilon \sim i.i.d.\ N(0, \sigma^2)$$

for $t \in [FY1985, FY2015]$.

where

- s_t is the 5-year moving average of annual schedule growth for active major MDAP contracts in year *t*,
- c_i are coefficient constants,
- Y_t is the variable of time (i.e., the model is a secular time trend),
- u_t is an autoregressive factor for the difference in the prior year between the actual schedule growth and the growth predicted by the other factors, and
- ε is a series of independent and identically distributed (*i.i.d.*) samples from a normal distribution with zero mean (i.e., Gaussian white noise).

Table 3 lists the coefficients c_i for the statistically significant factors in the model of the 5-year moving average of annual schedule growth on major MDAP contracts reporting EV.

Table 3. Model Coefficients and Statistics: 5-Year Moving Average of Annual Growth of Contract Schedules

Driver Type	Factor	MLE (OPG)	p-value MLE (OPG)
Linear declining trend	Coefficient for time trend (per year) (standard error)	−0.157% (0.000651)	0.014**
Self-Corrections	Autocorrelation coefficient: correction amount of actual-to-model difference in prior year (standard error)	0.766 (0.154)	0.000***
Base	Coefficient for constant (standard error)	3.21% (1.30)	0.016**

** statistically significant at the 5% level of significance

*** statistically significant at the 1% level of significance

NOTES: Annual 5-year moving average of schedule growth for executing contracts for major programs has a negative secular time trend over the last 31 years (i.e., schedule growth is declining). Each year's growth is the sum of all the changes in active contract schedules divided by the sum of all the original schedules. Thus, the portfolio percentage change will be closer in value to the percentage change of the longer contracts (similarly to how the growth in EV contract costs is affected by larger programs). The autocorrelation coefficient met stability conditions. After accounting for autocorrelation, the residual error was white noise.

Statistical Tests Employed

For estimation methods we employed Ordinary Least Squares (OLS) and Maximum Likelihood Estimation (MLE). For calculating the correct variance-covariance matrix we employed three different methods: Newey-West, Observed Information Matrix (OIM), and Sum of outer product of gradient vectors (OPG).

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